Substorm Evolution in the Near-Earth Plasma Sheet

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This grant represented one-year, phase-out funding for the project of the same name (NAG5-9110 to Boston University) to determine precursors and signatures of local substorm onset and how they evolve in the plasma sheet using the Geotail near-Earth database. We report here on two accomplishments: (1) Completion of an examination of plasma velocity signature at times of local onsets in the current disruption (CD) region. (2) Initial investigation into quantification of near-Earth flux-tube contents of injected plasma at times of substorm injections.

Local Onsets in the CD Region. In an attempt to find consistent evidence for an inside-out (Near-Earth Current Disruption (NECD) model) or outside-in (Near-Earth Neutral-Line (NENL) model) substorm evolution, we had previously examined the plasma velocity signature at local onset in the CD region. No preference for the direction of plasma flow at local substorm onset was found. This would be consistent with the NECD model for the substorm. However, it does not necessarily contradict the NENL model. Pre-local-onset earthward flow could have occurred on either side of the satellite, and the satellite could first observe the earthward flow, no flow, or a tailward responsive flow. Initial inspection of pre-dipolarization magnetic field and velocity signatures for a few selected events were consistent with a substorm current wedge approaching the satellite from the earthward side. Dipolarization and earthward plasma flow occurs as the substorm current wedge passes the satellite's position. This additional information would favor the NECD model, in which onset occurs earthward of Geotail's location ($X > -10\ R_E$) and expands outward. Consistency with an expanding current wedge and lack of consistent earthward flow at or before onset would strongly disfavor the NENL model.

Additional events have been examined, and it has become clear that for most events the initial velocity and field perturbations do not fit a simple picture of an expanding current wedge. In total, the observations better fit a NENL-model picture in which a near-Earth X-line (NEXL) located tailward of the satellite ($X < -15\ R_E$) creates reduced-population flux tubes (filaments/bubbles). These bubbles interchange with full-population flux tubes that were not involved in the reconnection process, resulting in substorm injection. In one-third of our events, Geotail was in the path of the bubble and saw prompt, fast, earthward flow coincident with dipolarization. An interpretation for the rest of the events is that Geotail was a bit to the side of the initial injection and saw flux tubes that did not undergo reconnection and were moving around the fast-moving bubble. Such an interpretation, together with Geotail observations taken further from Earth, seem to compare

favorably with results from various MHD simulations, e.g., results from the Lyon-Fedder-Mulberry MHD code reported at the Seventh International Conference on Substorms last March.

Quantification of Substorm Injections. Since the pressure-balance inconsistency was first elucidated [Erickson, G. M., and R. A. Wolf, Is Steady Convection Possible in the Earth's Magnetotail?, *Geophysical Research Letters*, 7, 897, 1980], it has been clear that the non-adiabatic release of plasma from plasma-sheet flux tubes is an essential feature of the magnetospheric substorm. Two questions have persisted since that time: (1) Where and how does this non-adiabatic process occur? (2) What value for flux-tube contents at the outer edge of the inner plasma sheet should be used in order to include the substorm phenomenon in M-I coupled models of magnetospheric convection such as the Rice Convection Model (RCM)?

The first question refers to the ongoing debate between the NECD and NENL models for the substorm. The second question addresses a long-standing, critical need for modelers in order to include the substorm in space-weather modeling. The proper specification of reduced-content flux tubes resulting from the substorm process is critical to properly specify ring-current injection and compute electric-field penetration to low latitudes. For models such as the RCM and ring-current models, the phase-space density in invariant terms is needed. For isotropic plasma, $PV^{5/3}$ of flux tubes entering the modeling region is needed. Here, V is the flux-tube volume, a quantity derived from the large-scale magnetic field. This quantity is not readily available from models such as the Tsyganenko magnetic field models that represent observational averages and cannot be expected to represent the instantaneous, large-scale magnetic field during a substorm reconfiguration. Indeed, the large-scale field depends on the instantaneous state of the plasma, and an independent, empirical means of determining $PV^{5/3}$s is needed as inputs to models such as the RCM or to truth-test global MHD models.

In collaboration with Richard Wolf at Rice University, we have been developing a very promising method to obtain flux-tube volumes from a point, satellite measurement of the magnetic field and plasma pressure. Exploiting the taillike nature of the magnetic field, force-balanced representations of the magnetic field based on Grad-Shafranov solutions are fit to actual, three-dimensional, force-balanced solutions for the magnetic field found by an equilibrium solver. The equilibrium solutions represent levels of activity ranging from quiet to stormtime, growth phase to substorm expansion with channels of depleted flux tubes. Using our flux-tube volume estimates, substorm depletion of flux tubes observed near Geotail perigee range from 40% to 80%. Based on our initial success, a proposal titled "Plasma-Sheet Source for Substorm Injections" has been submitted to the NASA Guest Investigator and Geospace Science SR&T programs. Here it is proposed to find empirically derived rules for specification of substorm depletions as functions of solar-wind conditions or energy input to provide that much needed boundary condition for M-I coupled convection models. As a second objective, comparison of the $PV^{5/3}$s of flux tubes injected at Geotail perigee with $PV^{5/3}$s of (dispersionless) injections measured at geosynchronous altitude provides a direct test of substorm models. The NECD model predicts significant, non-adiabatic loss from flux tubes in the inner plasma sheet (between Geotail's perigee and geosynchronous altitude), whereas the NENL model predicts the main non-adiabatic process occurs at the NEXL, somewhere tailward of where we are making the measurements.

Abstracts:

Erickson, G. M., N. C. Maynard, G. R. Wilson, Geotail Observations of Local Substorm Onsets at $-9\ R_E > X > -14\ R_E$, ICS-7, Lapland, Finland; March 21–27, 2004.

Presentations at Scientific Meetings:

Erickson, G. M., Genesis of Substorms in the Near-Earth Plasma Sheet, GEM/TS Workshop, Snowmass, 24 June 2003.